AN EVALUATION OF THE AMERICAN BUREAU OF SHIPPING RULES FOR THE TRANSVERSE FRAMING OF TANKERS

ALBERT GLENN STIRLING

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RULES FOR THE TRANSVERSE FRAMING OF TANKERS

by

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ABSTRACT

This thesis derives the fundamental conditions assumed by the American Bureau of Shipping in establishing their rules for the vertical side members of the transverse framing of tankers. The purpose of this is to allow other workers in the field to analyze these fundamental conditions and to substantiate their validiy.

It is assumed that the rules are based on simple beam theory. A comparison of the rules with simple beam theory determined a safety factor, and a condition of loading and end fixity. These results were analyzed for reasonableness and compatability. Once a set of conditions was definitely established, the IBM 704 electronic computer was used to check the ability of these conditions to duplicate the rule requirements for normal ships of 200 to 1000 feet in length. The machine also calculated the strength of the transverse web frame for a variety of conditions of corrosion.

The results of this procedure showed that the rules for the side transverse web frame could be duplicated by simple beam theory assuming twenty five percent end fixity, a safety factor of 2.5 based on the yield strength, and a beam of symmetrical and uniform cross section.

It also indicated that table 7 and table 7a of the rules, 1960 edition, are the required section moduli for the girder and girder web

respectively. Table 7 was found to include a safety factor equal to c, an undefined constant in the rules.

The results indicated that a corrosion of at least one tenth of an inch could be sustained in the side web frame without reducing the safety factor below one.

It remains for other workers to evaluate the bottom and deck transverses, and to correlate the results with those derived here. It is believed that a uniform safety factor, applicable through out the transverse framing system, will be found.

A study must also be made to determine the validity of the assumptions made by the American Bureau in deriving their rules, especially, the fundamental assumption that simple beam theory is applicable to the framing system.

The combination of these analyses will open the way to improvement and optimization of ship classification society requirements.

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I. INTRODUCTION

When ships are built for registry in the United States they are nearly always built to meet the requirements of the American Bureau of Shipping. These rules set the minimum structural and strength requirements of the hull. An engineer who is required to meet these minimums is justified in desiring to know the basis and/or background of these rules. Are they empirical, theoretical, or a combination of the two? Yet, here at the midpoint of the twentieth century, for all its automatic computing machines and advanced theories, this simple bit of information is not available and the engineer is expected to use these rules on blind faith.

The soundness of the American Bureau of Shipping Rules can not be argued. The record of the structural soundness of ships built to these rules speaks for itself. But on the other hand, what real proof is there that these ships are not ultraconservative and greatly over-designed? The initial construction sets the strength requirements throughout the life of the ship since all subsequent inspections for hull strength and soundness are judged satisfactory or unsatisfactory on the basis of the percentage of original material still intact. Therefore, in addition to the desire to perfect the science, there are economical reasons for the elimination of over-design in ship structures. As today's ships grow larger, the reduction of even a small percentage of material represents a considerable savings to the owners.

In the past decade, a tremendous advance has been made

which permits a more exact solution to the ship structure problem. This is the advent of the high speed electronic computer which is capable of reducing the time required for ship structure calculations from weeks and months to hours and days. Once programmed, a variety of similar complicated structures can be analysized in a minimum of time and the selection of the optimum design can be made.

An exact solution of the ship structure problem will probably never be obtained because of the varying nature of its loading and its motion in a seaway. However, an exact solution can be approached, and the present day methods must be improved to reach this ultimate in design. The quickest way to achieve these improvements is to convert the present day tables to equations and formulae for future development. It is granted that tables are one of the simplest ways of presenting data, but equations and mathematical formulae are the tools of the engineer, and only through them can he feel secure in his knowledge. Only through formulae can the engineer see what is fact and what is fiction, and offer constructive criticism; to quote Dr. George Vedeler, "Our rules (Det Norske Veritas) are by no means taboo; we invite criticism, because through criticism the science of naval architecture may advance." (11)

With these thoughts in mind, it is the object of this thesis to take The American Bureau of Shipping Rules for Building and Classing Steel Vessels section 28 (14) concerning the transverse framing of longitudinally framed oil tankers and to convert

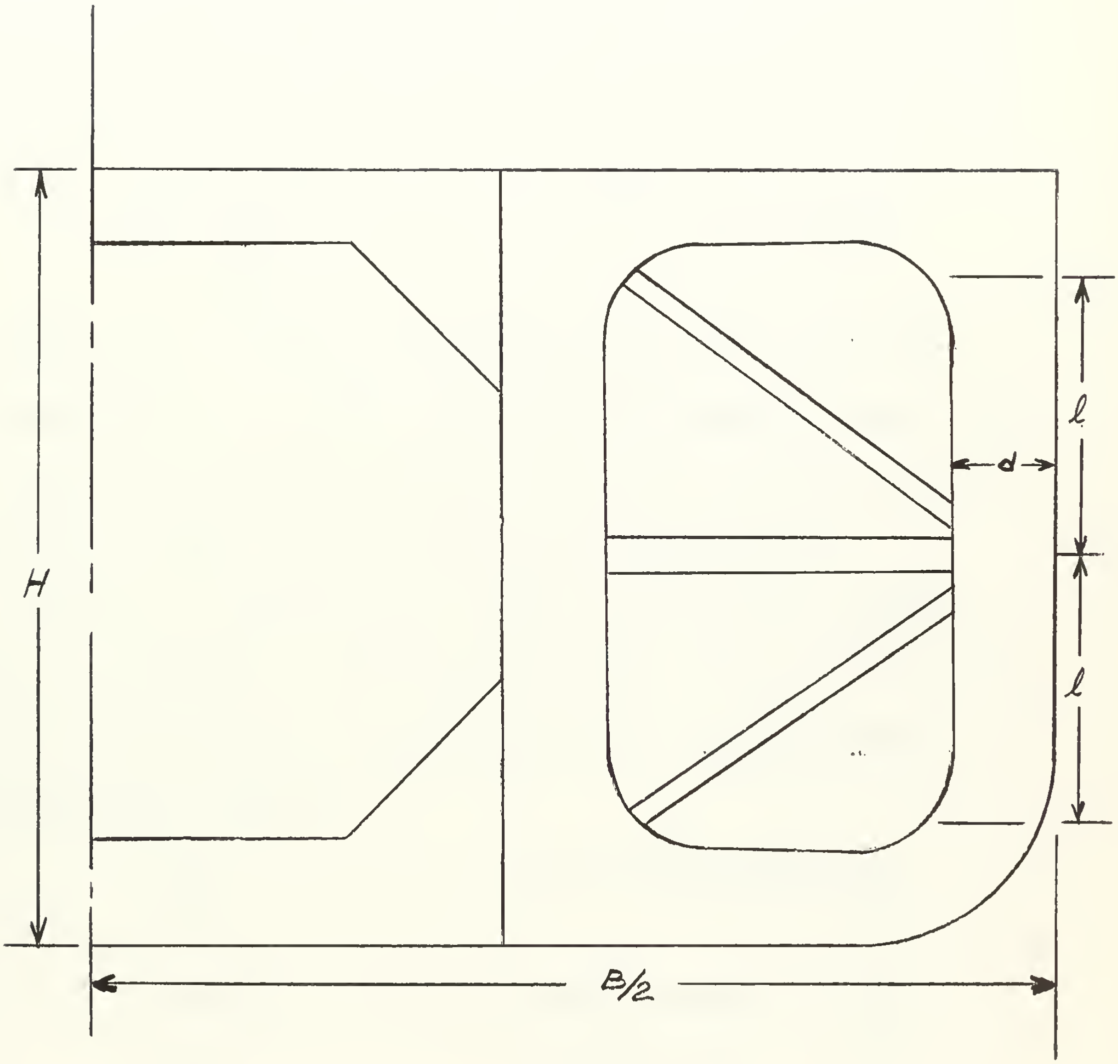
the rules and tables to equations. With the equations in hand, an attempt to correlate them with simple structural theory will be made to justify the derived equations and to separate the safety or experience factors from theory. The IBM 704 electronic computer will then be used to compute a large number of realistic structures by the ABS rules and by simple theory for the purpose of comparison. Corrosion allowances will also be applied to the rule values to see how the strength is allowed to vary with age. Also, these reduced sections will be compared with simple theory to see if any correlation exists. If justification for the derived equations is obtained then the way is open for future workers to criticize and improve the present theory.

SYMBOLS

A	Flange area	inches square
A'	Reduced flange area	inches square
a	Corrosion allowance	inches
B	Ship beam	feet
c	Factor given in the ABS rules, equals 2.5 for the cases considered in this thesis	
d	Depth of web	inches
f	As a subscript, refers to the flange	
H	Molded depth of ship	feet
h	Hydrostatic head	feet
h'	" " deck to top of stand pipe	feet
h"	" " to upper end of side span	feet
h_u	" " to middle of upper span	feet
h_L	" " " " " lower span	feet
I	Moment of inertia	
k	Constant in the moment equation dependent on the end constraint of the beam	
L	Ship length	feet
M	Bending Moment	foot-pounds
NG	An arbitrary constant defined in the ABS rules as equal to shc, and represents the beam loading	
SF	The safety factor	
s	Frame spacing as defined in the ABS rules, in this paper it shall be ten feet in all cases	
s	As a subscript, refers to the shell plating	
t	The girder web thickness	inches

w	Beam loading	pounds per foot
w	As a subscript, refers to the girder web	
y	The distance from the girder neutral axis to the outer most fiber	
Z	Girder section modulus	inches cubed
Z_g	Symbol assigned to represent the data from table 7	
Z_w	Symbol assigned to represent the data from table 7a	
ρ	Density of sea water taken to be 64 pounds per cubic foot	
σ	Stress in pounds per cubic inch	

Typical Midship Section



II. PROCEDURE

A study of the 1960 edition of The American Bureau of Shipping Rules for the Building and Classing of Steel Vessels section 28 (14) and tables 7 and 7a results in the following four equations which are given directly or can be readily deduced,

$NG = shc$		(1)
$Z_g = NG\ell^2/400$	table 7	(2)
$Z_w = td^2/6$	table 7a	(3)
$A = (Z_g - Z_w)/d$		(4)

The symbols used here and in all further equations in this work are those defined in the ABS rules and the accompanying symbol table. The symbols Z_g and Z_w are arbitrarily assigned to represent the values given in tables 7 and 7_a of the rules respectively.

The method of analysis to be applied to these four equations shall be a combination of dimensional analysis and a noting of similarities between these four equations and the following equations from simple beam theory.

$Z = I/y$	the section modulus	(5)
$Z = M/\sigma$	" " "	(6)
$M = w\ell^2/k$	bending moment	(7)
$w = sh\rho$	load per foot	(8)

Equation (4), which is a formulation of the example attached to table 7a, shall be examined first. The flange area (A) has the dimension of inches squared. The web depth (d) has the dimension inches, therefore, the two Z terms must have the dimension cubic inches for the equation to be dimensionally correct. This

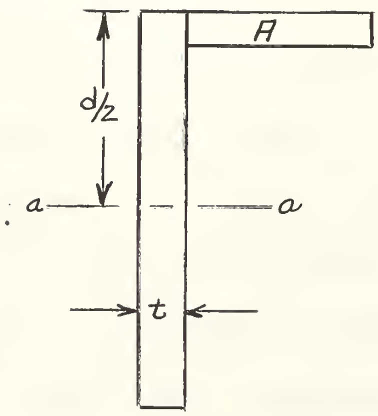
results in the Z terms having the same dimension as section moduli.

If equation (8) is substituted into equation (7) and that in turn substituted into equation (6) the following result for the section modulus is obtained.

$$Z = sh\rho\ell^2/k\sigma \qquad (9)$$

This is very similar in form to equation (2). Therefore, the assumption is made that the Z's in equation (4) do in fact represent section moduli.

Figure I
Beam Cross Section



Referring to Figure I, the moment of inertia of the web section about the center line axis aa is

$$I = td^3/12$$

and the section modulus according to equation (5) is

$$Z = td^2/6$$

which is exactly equation (3), the equation representing the values listed in table 7a. Therefore, table 7a is just a listing of section moduli for the web of a girder or beam, tabulated by depth and thickness.

The moment of inertia of the whole beam is derived from the equation

$$I_g = I_w + (d/2)^2 A_f + (d/2)^2 A_s \qquad (10)$$

If the assumption is now made that the effective area of the shell plating (A_s) is equal to the flange area (A_f) then equation (10) becomes

$$I_g = I_w + Ad^2/2$$

which, on rearranging and applying equation (5), becomes

$$A = (Z_g - Z_w)/d$$

This is exactly equation (4) which was to be derived.

Equations (3) and (4) then can be derived directly from simple beam theory, provided that the girder value (Z_g) of table 7 is in fact the girder section modulus and that the effective area of the shell plating is equal to the flange area. The term Z_g will be covered in detail in subsequent paragraphs. It remains only to justify the assumption concerning the effective area of the shell plating to prove the derivation of equation (4).

Assuming that the flange area and the effective shell plating area are equal is equivalent to assuming that the neutral axis of the girder remains centered on the web and is superimposed upon the web neutral axis. It is a fact of life that the determination of the effective area of the shell plating is a perplexing, if not impossible problem, and has to this time defied simple solution. Therefore, the only road open to the solution of the larger overall problem is to make some reasonable assumption concerning the effective contribution of the shell plating to the girder strength. The assumption, that the neutral axis remains centered, requires the largest flange area of all the possible assumptions, and therefore, is the most conservative assumption. In view of the conservative policies of the American Bureau of Shipping, it is believed that the above is indeed the true derivation of equations (3) and (4). A further and more detailed discussion of this point is in Section IV.

It now remains to prove that the girder value (Z_g) of table 7 is in fact the girder section modulus in cubic inches. Equation (9) is an equation derived for the section modulus of a beam. If equation (1) is substituted into equation (2), the result is identical with equation (9) if

$$\rho/k\sigma = c/400 \qquad (11)$$

It is firmly believed that the procedures and assumptions made to this point are correct, and that the proper interpretation of equation (11) is the key to the entire derivation of the ABS rules set forth in section 28. If the density (ρ) is in pounds per cubic foot, and the stress (σ) is in pounds per square inch, and c and k are dimensionless constants, then, for Z_g to be cubic inches, equation (11) must be corrected for dimensions to

$$k = \rho 4800/c\sigma \qquad (11a)$$

If the stress in equation (11) is considered to be an allowable stress, defined as the yield stress divided by a safety factor, then equation (11a) becomes

$$k = \rho (SF) 4800/c\sigma \qquad (11b)$$

where σ is now the yield stress.

It is well at this point to consider equation (11b) in great detail, and in so doing to consider several possible assumptions and/or engineering philosophies. Except for joints placed symmetrically about the center line, it is reasonable to assume that no two joints in a ship's structure have the same conditions of end fixity. It is also reasonable

to assume that the best structural design is one in which all the strength members are designed to the same factor of safety. In other words, no one section should be over-designed or designed to carry greater than its proportioned share of the load. Rewriting equation (11b) gives

$$kc/(SF) = \rho 4800/\sigma$$

or the left hand combination of terms is equal to a fixed constant. This is logical, for at any given position in the structure, c is given by the rules as some constant, SF is some designer's constant, and k is a constant depending on the end fixity of the beam. But, as one goes from position to position about the structure, k and c change; k because of the varying end conditions, and c by rule definition. Therefore, k and c must change in some fixed relationship to maintain their product a constant, or else the safety factor (SF) is not constant throughout the structure. There is one solution to this dilemma which is reasonable and meets all the desired requirements. This is to divide c into two factors, c' and c". c" is the factor of safety and is equal to SF. Assume k is an average end fixity condition which is approximately correct throughout the structure. c' then is a factor which corrects what is believed to be the correct end fixity, by calculations, empirical relations, or experience, to the assumed average value upon which the value c is based. In other words, to make use of tables, it is assumed that the structure has fixed end conditions and a variable factor of safety, when, in fact, it has variable end conditions and a fixed safety factor. The advantage of such a system is to allow

the use of one table for beams of any end constraint and to correct the table by means of a fictitious safety factor. Rather than complicate the nomenclature, the average end fixity condition will be solved by setting c equal to the safety factor (SF), and then solve for k. The numerical result is the same as if c was divided into its two component parts.

If a value of 32,000 psi, which is given in section 39 of the rules, is used for the yield stress in equation (11b), then k, the average assumed end constant, is equal to 48/5. Or the bending moment is

$$M = 5w\ell^2/48 \tag{7a}$$

This value of bending moment can be obtained from simple beam theory by assuming a uniformly shaped beam

(a) uniformly loaded, and with a condition of 25% end fixity imposed on each end, or

(b) uniformly loaded, and one end of the beam completely fixed and the other end only 50% fixed.

At this point, some of the calculations of Appendix B were carried out to compare the moment obtained by simple beam theory with a uniformly varying load and these end conditions, and with the assumed moment of $5w\ell^2/48$. This comparison gives some insight into the true safety factor, but the actual results are not too realistic because of the effects of a uniform load which is in fact superimposed on the varying load. In order to correct this deficiency in the calculations and to give a large number of results for plotting purposes, the

IBM 704 electronic computer is used to solve the problem as delineated in appendix B. Not only does this machine calculation solve the simple beam theory problem with a 25% end fixity, but it also solves the problem according to the rules. The rule moduli are then converted to beam shapes of varying flange thickness, and from these shapes a corrosion allowance is deducted and the reduced section moduli are calculated. These three results, simple beam theory, rule values, and the rule values reduced for corrosion are then examined and compared for justification of the assumptions made leading to these results.

III RESULTS

By Analysis

The mathematical analysis shown in section I gives the following results:

1. Table 7 of the American Bureau of Shipping rules is the required web frame girder section modulus for a symmetric girder tabulated by length of span and hydrostatic head.
2. Table 7a of the American Bureau of Shipping rules is the section modulus of the girder web tabulated by the thickness and the depth of the web.
3. The required flange area for the web frame girder is derived by assuming a symmetrical girder. That is, the neutral axis is centered on the girder web, and, the flange area and the effective shell plating area are equal. A subtle result of this assumption is that the effective shell plating area is also assumed.
4. The section moduli of table 7 are calculated on the basis of a uniformly distributed load, with a safety factor equal to c and based on the yield strength. The beam also is assumed to have either of the following end conditions;
   a) both ends twenty five percent fixed
   b) one end fully fixed and the other end fifty percent fixed.

End fixity as used here is defined in appendix B.

By Machine Calculation

From the results of the machine calculation the following table of section moduli was obtained.

Table I

Section Moduli

Lower Span ABS	Lower Span SBT	Lower Span ratio	Ship Length	Upper Span ABS	Upper Span SBT	Upper Span ratio
38.1	15.3	2.49	200	21.7	8.7	2.49
78.4	31.4	2.49	300	46.4	18.6	2.49
140.1	56.1	2.49	400	84.8	34.0	2.49
212.0	84.9	2.49	500	124.2	49.9	2.49
304.7	122.0	2.49	600	173.7	69.7	2.49
420.9	168.6	2.49	700	234.3	94.0	2.49
563.2	225.2	2.50	800	307.2	123.5	2.49
734.1	294.1	2.49	900	393.4	158.0	2.49
936.3	375.1	2.49	1000	494.0	198.7	2.49

The column headed ABS represents the section modulus required by the American Bureau of Shipping. The column headed SBT represents the section modulus required by simple beam theory with a factor of safety of one. This data is plotted in figures II and III. The following are the results of this data.

5. The constant ratio of the American Bureau of Shipping rules requirement to the simple beam theory requirement means that this probably is the condition upon which the rules are based, i.e. the beams are twenty five percent fixed at the ends.

6. Based on the head defined by the rules, the variation of the head over the length of span has very little effect on the total bending moment imposed on the beam and the assumption of a uniform head equal to the head at mid span is very, very good.

7. The factor of safety, on which the American Bureau of Shipping rules for the side transverse web frame is based, is 2.49 for all normal ships. This is for all practical purposes equal to the specified c value of 2.50. Therefore, it appears that c is the factor of safety.

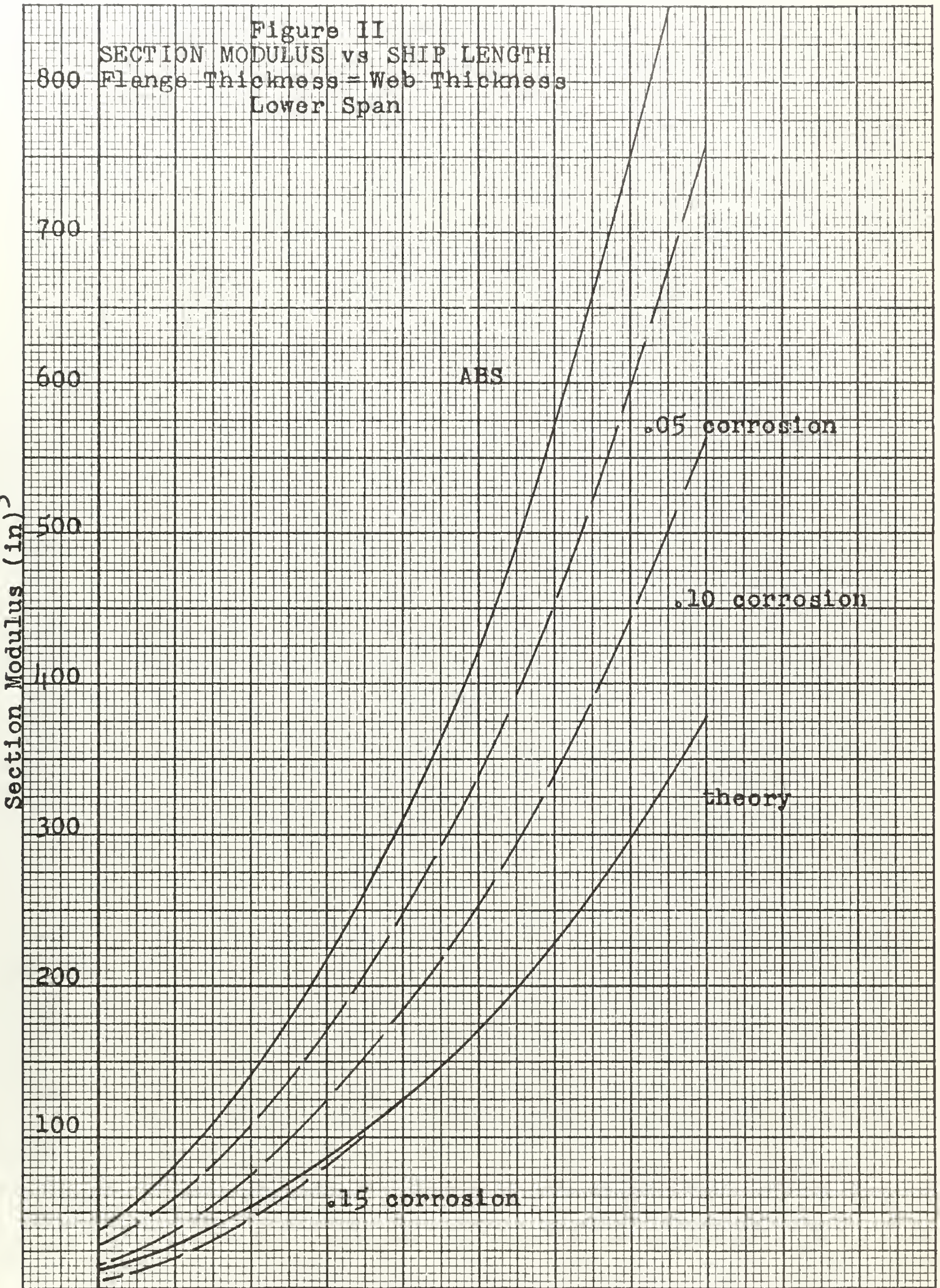


Figure II
SECTION MODULUS vs SHIP LENGTH
Flange Thickness = Web Thickness
Lower Span
800
700
600
500
400
300
200
100
Section Modulus (in)3
ABS
.05 corrosion
.10 corrosion
theory
.15 corrosion
200
400
600
800
1000
Ship Length (ft)

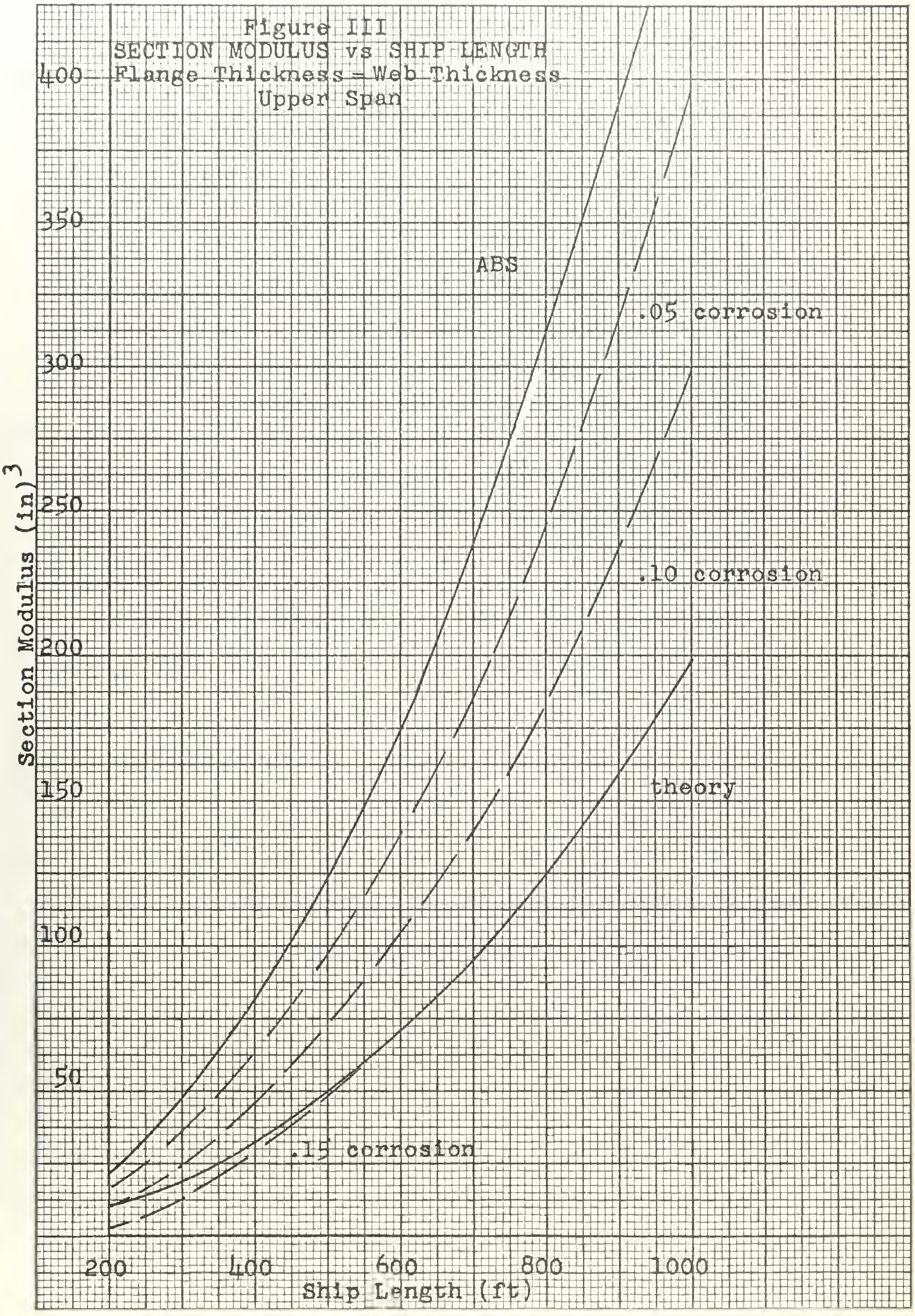


Figure III
SECTION MODULUS vs SHIP LENGTH
Flange Thickness = Web Thickness
Upper Span
ABS
.05 corrosion
.10 corrosion
theory
.15 corrosion
Section Modulus (in)^3
Ship Length (ft)
400
350
300
250
200
150
100
50
200
400
600
800
1000

The following results are deduced from the data plotted in figures IV, V, VI, and VII.

8. Regardless of the flange shape, all side transverse web frames in ships over two hundred feet in length, built to meet the American Bureau of Shipping rules, can withstand a uniform corrosion of one tenth of an inch and still retain the strength required by simple beam theory.

9. For ships six hundred feet and over, with the flange and web thicknesses equal to one half an inch, a uniform corrosion of fifteen one hundreds of an inch (.15") will reduce the section modulus of the rules to that required by simple beam theory. For ships less than six hundred feet in length, the maximum corrosion to reach simple beam theory requirements varies between ten and fifteen one hundreds of an inch.

10. For ships six hundred feet in length and over, with the flange thickness equal to one and one half times the web thickness, a uniform corrosion of two hundred and fifteen one thousands of an inch (.215") is required to reduce the rule value for side web frame girders to that of simple beam theory. See figure VII.

11. For all ship lengths the reduction in section modulus is linear with corrosion. That is, ten one hundreds of an inch (.10) causes twice the reduction in modulus that five one hundreds of an inch (.05) causes.

12. When the flange is twice the thickness of the web, for ships of five hundred feet and over, the web is corroded so much more in proportion to the flange, that the web will be annihilated before the beam has been corroded to the simple beam theory modulus.

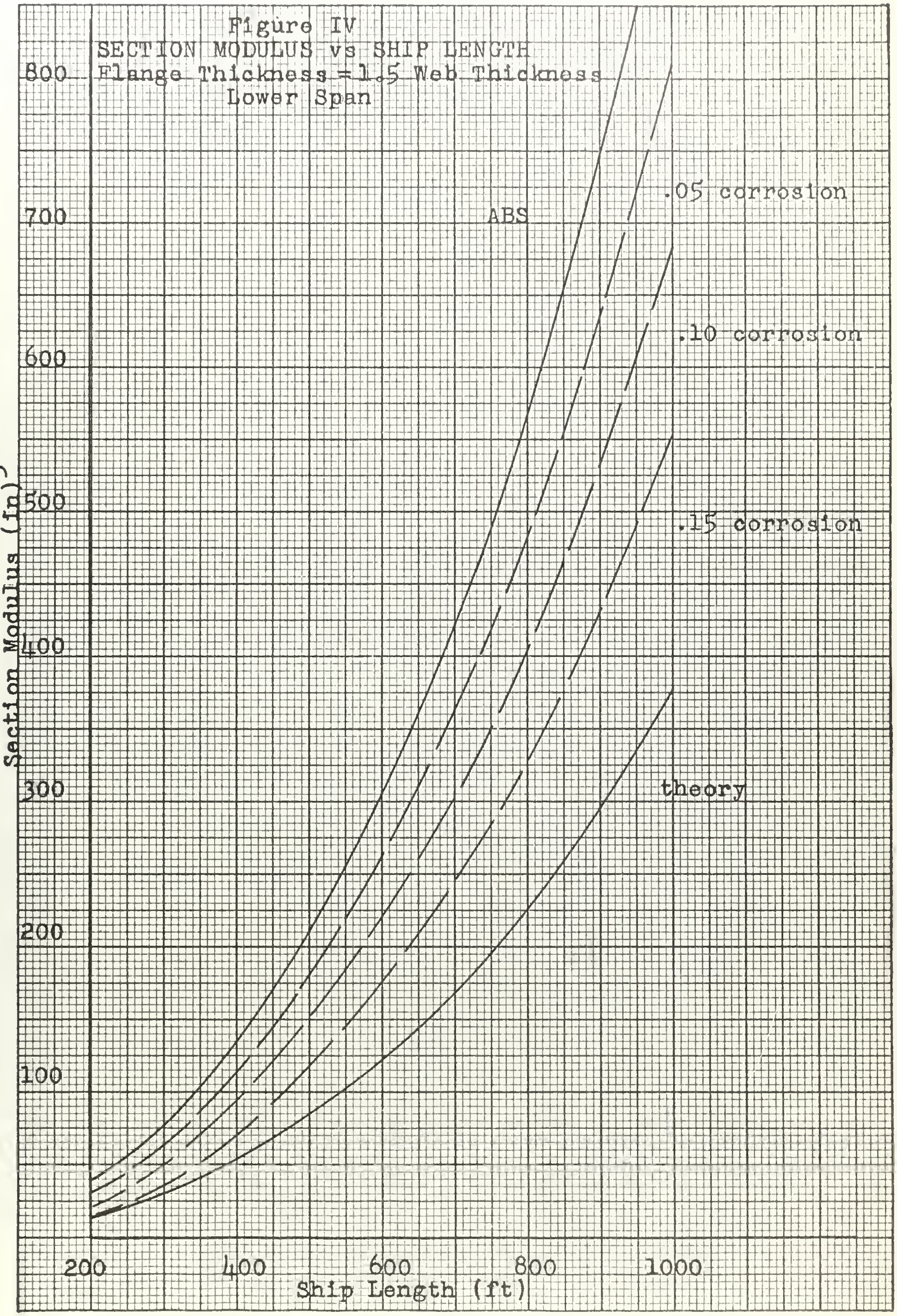


Figure IV
SECTION MODULUS vs SHIP LENGTH
Flange Thickness = 1.5 Web Thickness
Lower Span
ABS
.05 corrosion
.10 corrosion
.15 corrosion
theory
Section Modulus (in)^3
800
700
600
500
400
300
200
100
200
400
600
800
1000
Ship Length (ft)

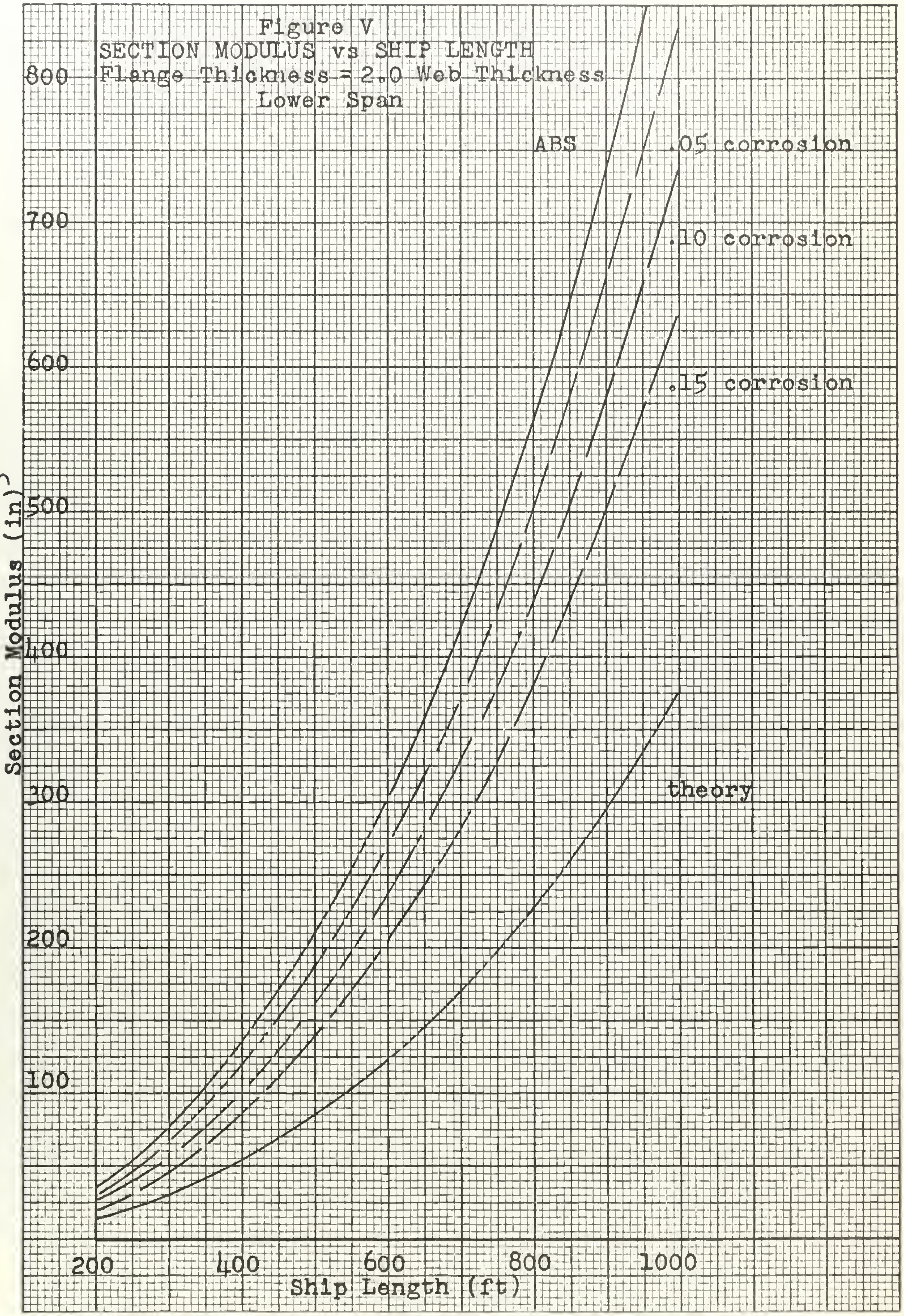


Figure V
SECTION MODULUS vs SHIP LENGTH
Flange Thickness = 2.0 Web Thickness
Lower Span
ABS
.05 corrosion
.10 corrosion
.15 corrosion
theory
800
700
600
500
400
300
200
100
200
400
600
800
1000
Ship Length (ft)
Section Modulus (in)^3

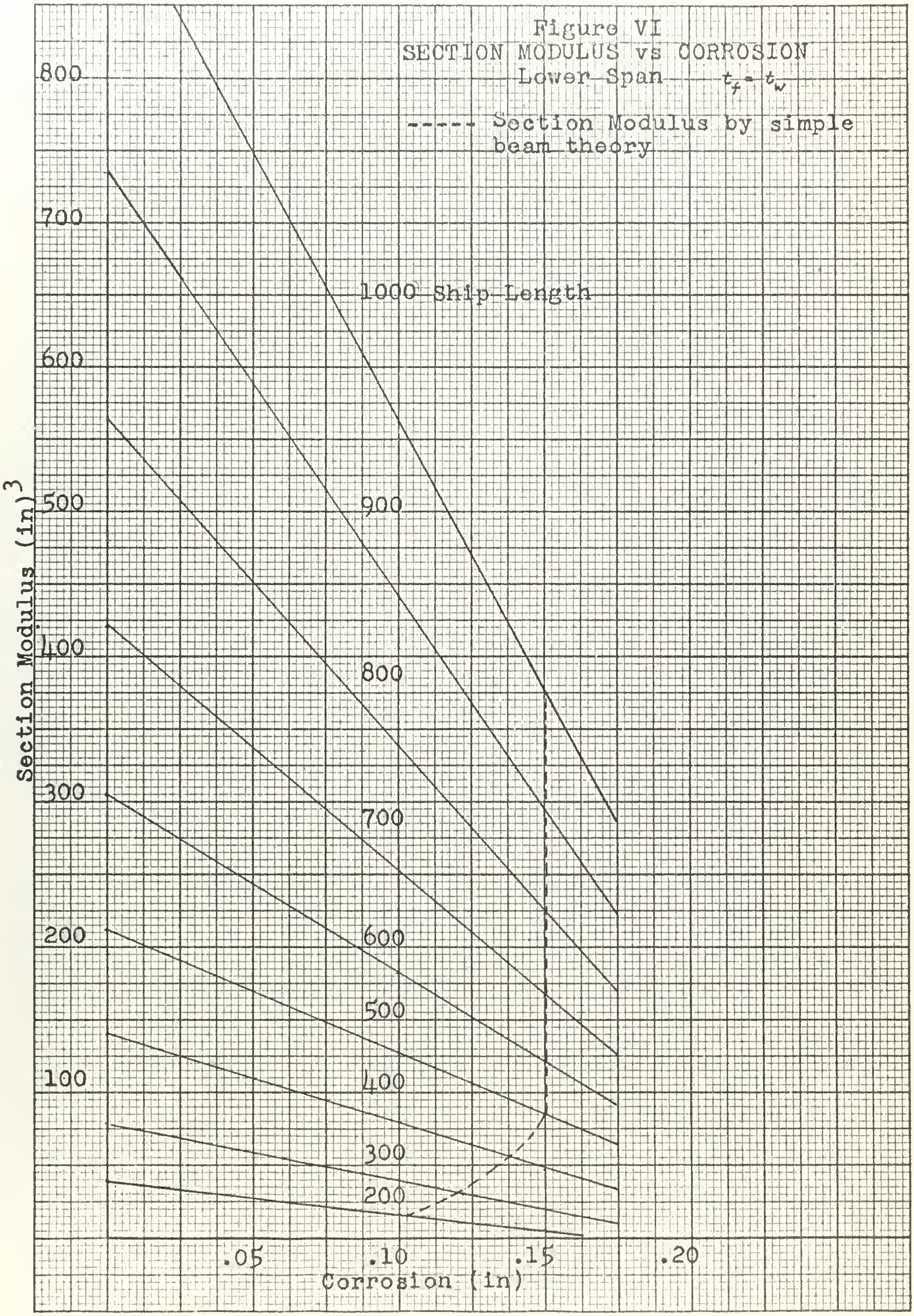


Figure VI
SECTION MODULUS vs CORROSION
Lower Span $t_f = t_w$
----- Section Modulus by simple beam theory
1000 Ship Length
900
800
700
600
500
400
300
200
Section Modulus $(in)^3$
800
700
600
500
400
300
200
100
.05
.10
.15
.20
Corrosion (in)

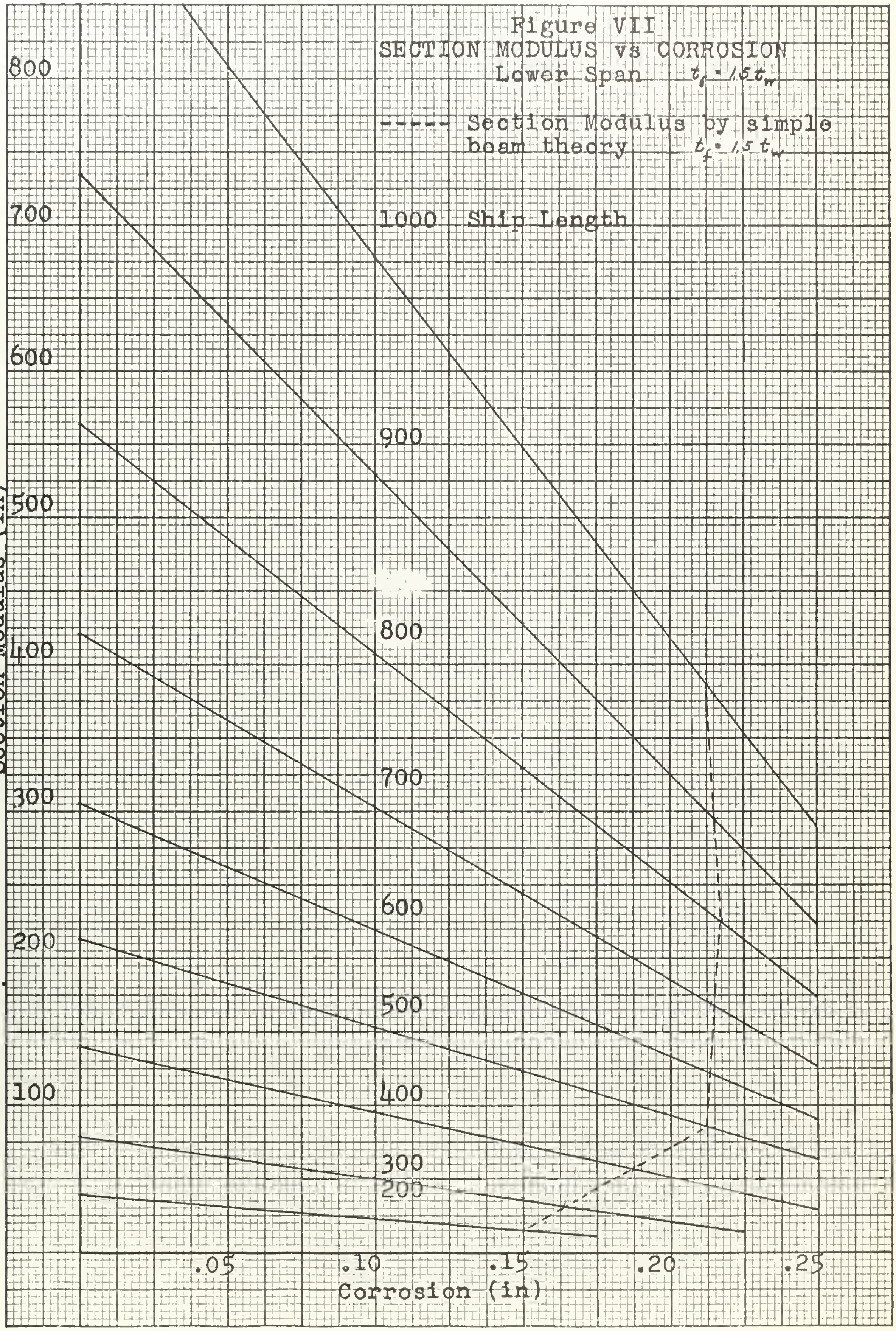


Figure VII
SECTION MODULUS vs CORROSION
Lower Span $t_f = 1.5 t_w$
----- Section Modulus by simple beam theory $t_f = 1.5 t_w$
1000 Ship Length
900
800
700
600
500
400
300
200
800
700
600
500
400
300
200
100
Section Modulus (in)^3
.05
.10
.15
.20
.25
Corrosion (in)

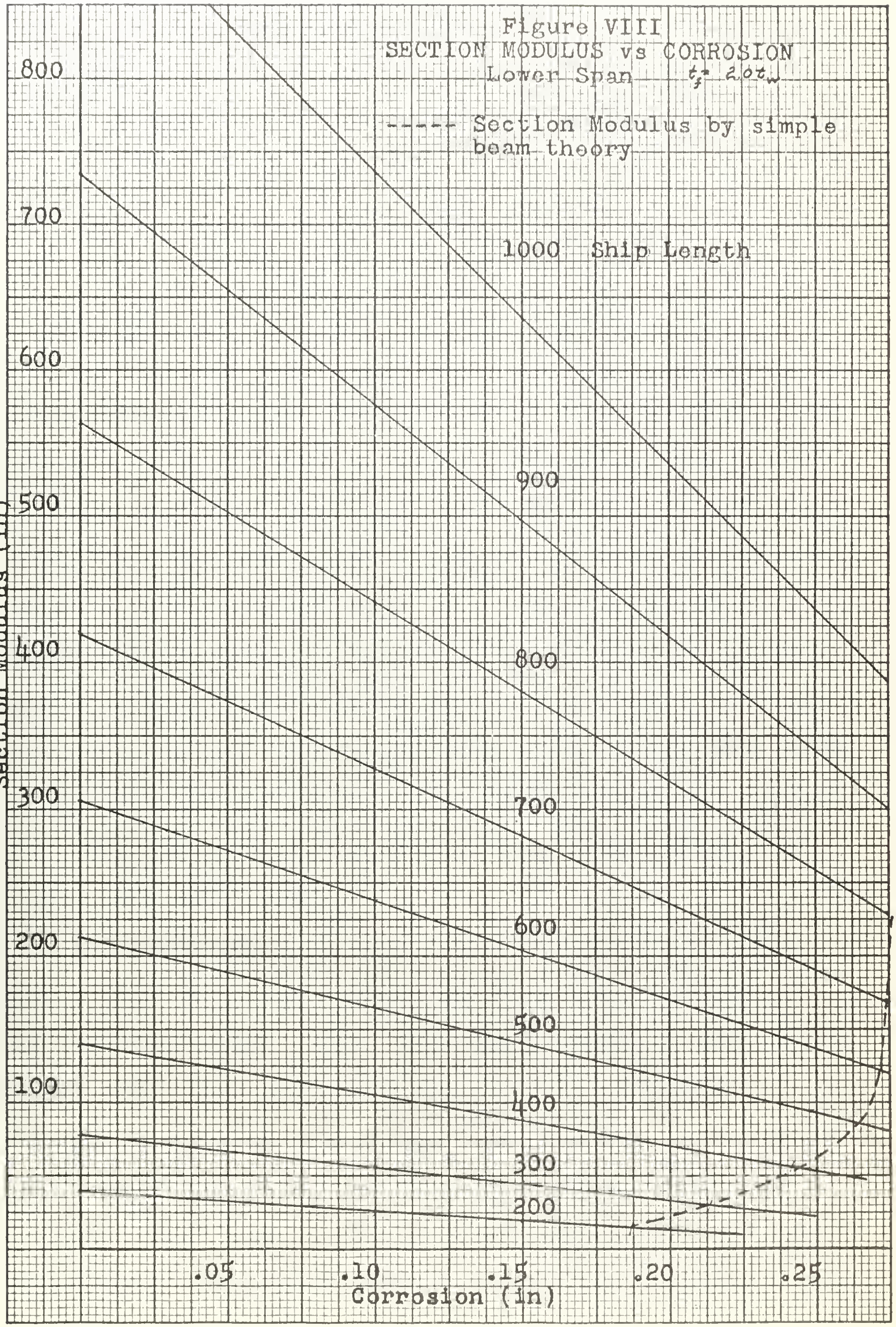


Figure VIII
SECTION MODULUS vs CORROSION
Lower Span $t_f = 2.0 t_w$
----- Section Modulus by simple beam theory
1000 Ship Length
900
800
700
600
500
400
300
200
Section Modulus $(in)^3$
800
700
600
500
400
300
200
100
.05
.10
.15
.20
.25
Corrosion (in)

IV. DISCUSSION OF RESULTS

Flange Area

It has been shown that the only way to derive equation (4) is to assume that the neutral axis remains centered, and therefore, the effective shell plating area and the flange area are equal. What is the significance of such an assumption? This assumption in effect sets the contributing width of shell plating to the girder strength, since the equation calculates the area. What happens if the effective shell plating area varies from this assumed value? To better understand these effects a look at the stresses present in the girder seems in order. In the flange the only loading present is the overall end compression or tension (girder stress), and the loading due to the bending moment of the external hydrostatic head. In the shell plating there is, in addition, the plate bending stress. If the flange and the plating are of the same material, the allowable bending stress in the flange is greater than that of the plating to maintain the same total stress in each section of the girder. If the neutral axis remains centered, i.e. the areas are equal, then the flange may have a smaller area for the same total stress.

If the effective shell plating is greater than assumed, the girder moment of inertia increases and the neutral axis moves toward the shell plating. Since the moment of inertia increases more rapidly than the neutral axis shifts, the section modulus is increased. This results in a stronger beam. The shift in the neutral axis is beneficial in that the stress in the flange is increased relative to that in the plating and a more uniform stress distribution results. The absolute value of stress in the flange may increase

or decrease since the increase in section modulus reduces the total stress in the beam. The resultant change of stress in the flange depends on the relative change in the total stress of the beam and the shift of the neutral axis.

Now, what happens if the actual plating area is less than the assumed value? If this occurs the design is in trouble. The question then becomes, how probable is it that the actual plating area is less than the assumed value. From the computer solution the flange area for ship lengths of 200 and 1000 feet are 3.4 and 30.1 square inches respectively. If the plating thickness is one half inch, the effective widths are 7.8 and 60.2 inches respectively. Thicker plating would reduce these widths. In normal ships, the webs are placed every eight to ten feet and therefore, in normal circumstances the effective area of the plating will be greater than the required assumed values. The conditions of excess plating area as described in the preceding paragraph will be the normal condition.

The assumption of equal areas is satisfactory in all normal ship structures.

Beam Loading

If the derivations thus far in this work are correct, it appears that the only loading considered in the design of the transverse framing is the hydrostatic loading. Since no consideration of the cargo loading is mentioned in the rules, the condition of loading considered must be with the ship at load draft and with the tanks empty. The hydrostatic head is four to eight feet above the deck depending on the ship length. Except for the height of head, no argument can be made against this assumed condition.

What is the basis of the head requirements of the ABS rules? The indications are that the possible internal loadings which might occur during cargo handling set the head requirements. The rules state that the head shall be four to eight feet depending on ship length, but in no case shall the head be less than that to the top of the hatch covers. One such case would be the ship in drydock and the tank being hydrostatically tested. An alternative may be that these head requirements are reasonable estimates of the pressure built up in the tank in the event of an overflow.

The final condition imposed is that of no axial load. Tankers differ from conventional cargo ships in that the transverse bulkheads are spaced much closer together. Generally, forty feet is the accepted length of tank. Since the compression of a bulkhead is very slight, and the stiffening is designed to prevent bending, the assumption that the bulkhead may be considered rigid in the vertical direction seems to be quite valid. Therefore, the bulkheads tend to greatly reduce any vertical load imposed on the frame. This section of the rules considers tankers exclusively, therefore, deck loading other than superstructure and free water may be neglected. It seems then, that the only possible axial loads on the frames consists of the structure itself, the force of buoyancy, and any water on deck. The structure weight and the force of buoyancy tend to be dissipated as shear forces in the plating and frames. The free water on deck is a temporary condition and more nearly dynamic in nature. In view of the apparent simplicity of the rules it is believed that dynamic effects are neglected and that the safety factor is sufficient to meet dynamic requirements. In view of these

considerations it is believed that the rules for the transverse framing are based only on loading normal to the axis of the frame.

End Fixity

Probably the most important of all the conclusions to be drawn from this thesis is the assumed end fixity of the beams. The true end conditions have not been derived here, for that is a thesis in itself. It has been shown that there are two types of end fixity which result in the same bending moment as that assumed in the rules. In both types the loading is uniform over the length of the span. These two end conditions are:

(a) both ends twenty five percent fixed.

(b) one end fully fixed and the other end fifty percent fixed.

The definition of end fixity as used here is given in appendix B.

When one studies a typical tanker section as shown on page 5a, it is seen that both of these conditions have possibilities. Consider the upper side span. With the K strut acting as a rigid column and with the loading on the lower span being greater than that on the upper span, it is easily seen how the upper span could appear fixed at the strut. At the same time the upper end of the upper span would appear only partially fixed since there is no deck load to restrain the deck from bulging upward and allowing the joint of deck and side to rotate. Thus the condition of one end fully fixed and the other fifty percent fixed could apply to this span. However, the condition that both ends are only twenty five percent fixed could also be argued. Only a detailed analysis could decide the issue.

By similar logic it is seen that either condition might also apply

to the lower side span. In this case, the upper end at the strut would appear partially fixed in relation to the lower end which is fixed by the massive structure at the turn of the bilge. Here again, it is possible to say that neither end is fully fixed and that the condition of twenty five percent end fixity is more applicable.

The center deck and bottom spans between the longitudinal bulkheads are symmetrical and loaded uniformly. In view of the stiffness of the longitudinal bulkheads and the massive brackets, the spans appear to be fully fixed. The shorter side spans of the wing tanks are not felt to be derivable from beam theory because of their non-uniform shape and the small length to depth ratio.

In all of the preceding, the reader may not agree with the assumed end conditions. On the validity structure-wise of these assumptions the author has no argument. It can only be stressed that the intent of this thesis is to deduce the basis of the American Bureau of Shipping rules and not to judge their correctness. Therefore, reasonability is the only requirement for consideration in this work.

<u>The Factor of Safety</u>

The correct determination of this factor will or will not help to justify all previous assumptions. Here in one small number, a multitude of previous sins can be corrected and adjusted. Dynamic effects, incorrect end fixity, and experience can all be accounted by the phase, "the safety factor allows for it."

In order to get started on an analysis, it was assumed that c was the factor of safety. On this ground, a set of end conditions were derived and evaluated. Based on the derived end conditions, the c value was adjusted to a more realistic value by considering hydrostatic type loading instead of uniform loading. A tablulation of these results is given in appendix C.

The important thing to note about the results of the corrected values of c is that there appears to be correlation between the value for side and bottom. For the side span loaded hydrostatically, and fifty percent fixed at its upper end and fully fixed at the bottom, the corrected value of c is 2.23. For the bottom spans fully fixed at each end the corrected value of c is 2.19. Thus, it seems as though there may be some justification in the assumption that there should be a uniform safety factor throughout the structure.

The results of the computer solution, shown in figures II and III, show that for the defined head and the derived end condition of twenty five percent end fixity, the safety factor is equal to 2.49 in the side span. Theoretically, the safety factor can never reach 2.50 since this requires a uniform load for the prescribed conditions. Normal hydrostatic loading can only approach this value. To the author, this ability to duplicate the American Bureau of Shipping requirements over all normal ship lengths indicates that c is in fact the factor of safety assumed by the Bureau in defining its rules, and these are the conditions of loading and end fixity assumed by the Bureau. It also shows that the assumption of uniform loading equal to the mid span head is a very good approximation.

The problem with the results of the previous paragraphs is that any correlation in safety factor between the side and the bottom is destroyed or at least put in serious question. The value of c for the bottom is 1.75, and as shown above, by assuming fully fixed end conditions can be adjusted to a value of 2.19. The only justification for this being less than the value in the side spans, is the effect of the keel. With bulkheads spaced at least every forty feet, and considering the size and construction of the keel in modern tankers, the keel is sure to act as a support at mid span for the bottom transverse frames.

There is also the problem of correlating the safety factor between the deck and the side, and correlating the end fixity of deck and bottom spans. The c value for the deck is specified as 2.5, the same as that of the side. If it is assumed that the end conditions are twenty five percent fixed, then there is complete agreement in the safety factor side and deck. On the other hand however, the construction of the deck and bottom spans are very nearly identical. Only the size and weight of material are different. Since the deck load is also proportionately less than the bottom load, it appears that the deck and bottom must be assumed to have the same end conditions. There is thus created a paradox. If the deck is assumed fully fixed as is the bottom, then the c value is corrected to 3.12. The only validation for a safety factor this much higher in the deck than in the side is that axial loads are more apt to be present in the deck transverses. However, the ship is symmetrical and therefore these axial loads should appear in the bottom transverses where the safety factor is lower than in the sides. Again a paradox

is created. A solution to this problem is not knowingly presented here. The work here was aimed primarily at the side span in the thought that the side span was the key, and that the other spans would be open to simple deduction once the side span solution was obtained. Obviously this is not the case.

The final result obtained was the effect of corrosion on the structural strength of the members. The results discussed here are plotted in figures II thru VIII inclusive. Corrosion, or destruction of material by corrosion, is a function of surface area and therefore structural shape. Shape was considered here by a ratio of flange thickness to web thickness.

In figures II and III it is seen that if the flange is at least the same thickness as the web, that in any length ship, as much as one tenth of an inch (.10) of uniform corrosion can occur and the structure will still retain the section modulus required by simple beam theory. This means that the web will sustain between forty and fifty nine percent destruction and still retain the required section modulus. Granted, this is not the sole criteria for strength since a girder with flanges twice the web thickness will have the web annihilated and still retain the required modulus, that is, until the flanges fall together and the structure collapses into a pile of rust. The point is, that corrosion or at least the thought that corrosion will occur, helps to account for such a large safety factor as the rules prescribe.

V CONCLUSIONS

It is the conclusion of this thesis that the rules for the transverse framing of tankers as delineated by the American Bureau of Shipping are based on simple beam theory. And, that in particular regard to the vertical side transverse web frame, the following assumptions were made by the American Bureau as a basis for applying the simple beam theory.

1. The required section modulus of the girder is calculated on the basis of a symmetrical section. The flange area and the effective shell plating area are assumed equal.

2. The beam strength is calculated for bending stresses due to a uniform load normal to the beams longitudinal axis, and no axial loads are assumed present.

3. The bending moment is calculated for a beam with twenty five percent end fixity and a uniform cross section.

4. A factor of safety of 2.5 and equal to c is assumed for the particular case of the side transverse. This factor of safety is based on a yield stress of mild steel of 32,000 psi.

5. Table 7 and table 7a of the American Bureau of Shipping Rules for Building and Classing Steel Vessels, 1960, are tables of section moduli. Table 7 is for the girder and is based on girders with twenty five percent end fixity, a factor of safety equal to c, and a uniform load equal to the hydrostatic head at mid span. Table 7a is the section modulus of the girder web. Both tables have dimensions of cubic inches.

It is also concluded that one reason for the large value of the factor of safety is the need for a corrosion allowance of some magnitude to insure profitable operation and a minimum of structural replacement over the life of the ship. It has been shown that a uniform corrosion of one tenth of an inch or more, depending on ship size and girder shape, is allowable before the safety factor is reduced to one.

Finally, it is believed that the intent and purpose of all the assumptions made by the American Bureau of Shipping were to simplify the calculations and yet retain an adequate factor of safety.

VI RECOMMENDATIONS

As stated in the introduction, it was the purpose of this thesis to determine the basis of the rules of the American Bureau of Shipping which apply to the transverse framing of tankers. The results obtained have been judged only on reasonableness and the ability to duplicate the American Bureau requirements. This work primarily sought the solution of the side member of the transverse frame in hopes that it was the key to the whole frame analysis, and that once it was solved, the deck, bottom, and bulkhead transverse framing would fall into place. Unfortunately, the other structural members have not been so cooperative, and time has limited their study. Therefore the following recommendations are made.

1. An analysis of the bottom and deck beams must be made to determine the origin of the rules for these members. In particular, it should be attempted to correlate the safety factor of the side with these members. It is firmly believed that a constant factor of safety will be found.

2. Once the origin of the rules is determined, a study should be made to determine the correctness and adequacy of the basic assumptions, such as the end conditions, the assumed girder shape, and the safety factor.

3. Finally, it is felt that the other members will be found to be derivable from simple beam theory. Therefore, an analysis must be made to consider the validity of using simple beam theory on the structural members involved in a ship framing system. The length

to depth ratio of the beam is small, generally the beams are not of uniform cross section or size throughout the length of the span, and finally, the ends are fixed by brackets which extend over a considerable length of the beams. All of these seriously effect the criteria upon which simple beam theory is based.

Only when the above items have been accomplished will the designer know all the strengths and weaknesses of his design. Only then will the present day methods of transverse framing design be open to improvement and optimization.

VII APPENDIX

APPENDIX A

The information in the following appendices represents only those calculations deemed necessary for the completeness of the thesis, and not all the calculations done or considered in maintaining the thesis on its final course. The work presented in these appendices are in turn greatly abbreviated and represent only an outline and the important results. The methods of the calculations are shown and equation by equation results are given so that the interested reader may easily check the work.

The program for the IBM 704 was written in the Share Assembly Program code. The program was very straight forward and included only one subroutine (square roots). The program would not be easily altered to other end conditions. The calculations of the American Bureau of Shipping rules and the effects of corrosion on the rules, are complete and values desired can be read from the graphs of figures II through VII in the text. However, for those interested the program is on file with the Department of Naval Architecture and at the Computation Center at the Massachusetts Institute of Technology.

APPENDIX B

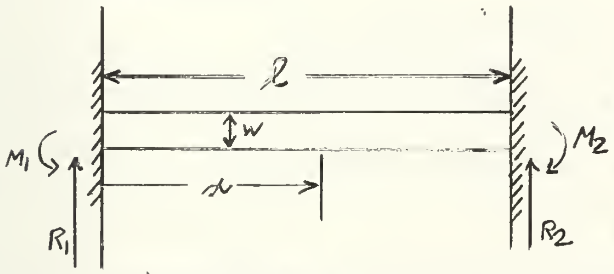
Details of the Procedure

End Fixity

As used in this thesis, the end fixity of a beam is defined as the factor by which the end moment of a fully fixed beam is multiplied to obtain the value of the end moment of a beam only partially fixed. As an example, the end moment of a fixed end beam is $w\ell^2/12$ while for the same beam only 25% fixed the end moment would be $w\ell^2/48$.

Beam Calculations

a) A uniform beam with uniform loading and fully fixed end constraints



$R_1 = R_2 = w\ell/2$

$M_1 = M_2 = w\ell^2/12$

$w = s\rho\ell$

$M_x = M_i - R_i x$

b) A uniform beam with uniform loading and with a 25% end fixity at each end

$R_1 = R_2 = w\ell/2$ $\qquad$ $M\ (x = \ell/2) = 5w\ell^2/48$

$M_1 = M_2 = w\ell^2/48$ $\qquad$ $M_x = M_i - R_i x$

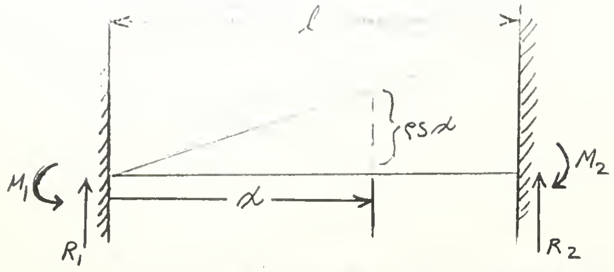
c) A uniform beam with uniform loading with end 1 fully fixed and end 2 50% fixed

$R_1 = 7\rho s\ell^2/16$ $\qquad$ $M_1 = 5\rho s\ell^3/48$

$R_2 = 9\rho s\ell^2/16$ $\qquad$ $M_2 = \rho s\ell^3/24$

d) A uniform beam with a uniformly varying load with fully fixed end conditions

$R_1 = 3\rho s\ell^2/20$ $\qquad$ $R_2 = 7\rho s\ell^2/20$



$$M_1 = \rho s \ell^3/30$$
$$M_2 = \rho s \ell^3/20$$
$$M_x = R_1 x - M_1 - \rho s x^3/20$$

e) A uniform beam with a uniformly varying load with each end 25% fixed

$R_1 = 13\rho s \ell^2/80$ $\qquad$ $M_1 = \rho s \ell^3/120$

$R_2 = 27\rho s \ell^2/80$ $\qquad$ $M_2 = \rho s \ell^3/80$

$$M_x = R_1 x - M_1 - \rho s x^3/6$$

f) A uniform beam with a uniformly varying load with end 2 fully fixed and end 1 50% fixed

$R_1 = \rho s \ell^2/8$ $\qquad$ $M_1 = \rho s \ell^3/60$

$R_2 = 3\rho s \ell^2/8$ $\qquad$ $M_2 = 7\rho s \ell^3/120$

$$M_x = R_1 x - M_1 - \rho s x^3/6$$

g) A uniform beam with a uniformly varying load with end 1 fully fixed and end 2 50% fixed

$R_1 = 3\rho s \ell^2/16$ $\qquad$ $M_1 = 11\rho s \ell^3/240$

$R_2 = 5\rho s \ell^2/16$ $\qquad$ $M_2 = \rho s \ell^3/40$

$M_x = R_2 y - M_2 - \rho s \ell^2 y/2 + \rho s y^3/6$ $\qquad$ where $y = (\ell - x)$

Safety Factor Calculations

Subscript R denotes the real safety factor on the basis of the assumed end condition

$$(SF)_R M_R = cM$$
$$(SF)_R = cM/M_R$$

The Computer Problem

The problem, to be solved by the IBM 704 computer, is to find the section modulus of the transverse side frame by simple

beam theory assuming 25% end fixity, and also, to solve for the section modulus by means of the ABS rules. Ship length (L) is the given parameter and a K type strut is assumed. The calculation then solves for the ship's dimensions, and for the section modulus for both the upper and lower spans. Three girder shapes are defined using a flange thickness equal to one, one and one half, and two times the web thickness. Five corrosion allowances are then deducted from the girder and the reduced section modulus calculated. The problem as solved by the computer is mathematically defined below.

a) Given ship length (L) find the hydrostatic head (h), i.e. the loading, on the transverse

$$B = L/10 + 20 \tag{1}$$

$$H = B/2.5 \tag{2}$$

$$h' = 4 \text{ if } L \leq 200 \quad \text{linear between values} \tag{3}$$
$$= 8 \text{ if } L \geq 400$$

$$\ell = 0.4H \tag{4}$$

$$h_L = h' + 0.08H + 1.5\ell \tag{5a}$$

$$h_u = h' + 0.08H + 0.5\ell \tag{5b}$$

b) Find the section modulus (Z) by simple beam theory

$$h'' = \begin{Bmatrix} h_L \\ h_u \end{Bmatrix} - 0.5\ell \tag{6}$$

point of maximum moment

$$x = -h'' + \left\{(h'')^2 + 13\ell^2/40 + h''\ell\right\}^{1/2} \tag{7}$$

maximum moment

$$M_x = \rho s\left\{13\ell^2 x/80 + h''\ell x/2 - x^3/6 - \ell^3/120 - h''\ell^2/48 - h'' x^2/2\right\} \tag{8}$$

$$Z = 12M_x/\sigma \tag{9}$$

c) Section modulus by ABS rules

$$Z = NG\ell^2/400 = h\ell^2/16 \tag{10}$$

d) Find the girder shape

$$t = .32 \text{ if } L \leq 150 \quad \text{linear between values} \tag{11}$$
$$= .50 \text{ if } L \geq 500$$

$$d = 1.5\ell \tag{12}$$

$$Z_w = td^2/6 \tag{13}$$

$$A = (Z-Z_w)/d \tag{14}$$

$$W_f = A/t_f \tag{15a}$$

$$t_f = t_w,\ 1.5t_w,\ 2t_w \qquad t_w = t \tag{15b}$$

e) Find the modulus of the reduced section

$$A' = w_f(t_f-2a) \tag{16}$$

$$Z_w' = (t-2a)d^2/6 \tag{17}$$

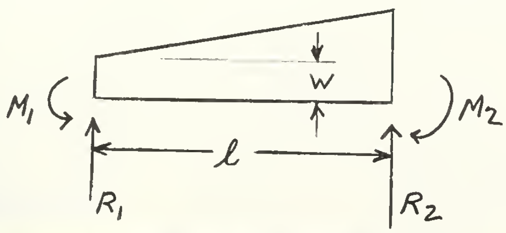
$$Z' = Z_w' + dA' \tag{18}$$

$$a = .05,\ .075,\ .10,\ .125,\ .150$$

APPENDIX C

Summary of Data and Calculations

Results of Safety Factor Calculations



1. Beam 25% fixed at each end

Load	M_r	M_a	SF
$w = 0$	$0.0535\rho s\ell^3$	$5\rho s\ell^3/96$	2.43
$w = s\ell/2$	$0.105\rho s\ell^3$	$5\rho s\ell^3/48$	2.48

2. Beam 50% fixed at end 1 and fully fixed at end 2

Load	M_r	M_a	SF
$w = 0$	$7\rho s\ell^3/120$	$5\rho s\ell^3/96$	2.23
$w = \rho s\ell/8$	$137\rho s\ell^3/1920$	$25\rho s\ell^3/384$	2.28
$w = \rho s\ell/2$	$53\rho s\ell^3/480$	$5\rho s\ell^3/48$	2.36

3 Beam fully fixed at end 1 and 50% fixed at end 2

Load	M_r	M_a	SF
$w = 0$	$11\rho s\ell^3/240$	$5\rho s\ell^3/96$	2.84
$w = \rho s\ell/8$	$103\rho s\ell^3/1920$	$125\rho s\ell^3/1920$	3.04

4. Beam uniformly loaded and fully fixed at each end. In this case the bottom is being considered and c is 1.75.

$w\ell^2/12$	$5w\ell^2/48$	2.19

5. Similar to 4 except that the beam is in simple support.

$w\ell^2/8$	$5w\ell^2 48$	1.46

The data on the following nine pages consists of the results of the IBM 704 machine calculation as delineated in Appendix B. As a matter of interest the total machine time for this problem was two and two tenths minutes of which only seven tenths was actual calculation time and the remainder was used to introduce and print out the problem and the answers.

The format is generally self-explanatory and requires little explanation. The table of reduced flange area and reduced section modulus has the following form. The columns are the values with corrosion allowances of, from left to right, .05, .075, .10, .125, and .150 inches. The first three rows are for the lower span and the second three rows are for the upper span. The three rows represent flange thicknesses of one, one and one half, and two times the web thickness.

The only information not given is the span length which can be calculated by the following equation.

$$\ell = (2L + 400)/125$$

Length 200

Lower Span		Upper Span
	Position of Maximum Moment	
3.3029		3.3792
	Section Modulus Beam Theory	
15.256		8.717
	Rule Value	
38.093		21.709
	Flange Area	
3.41		1.71

Flange Width

Lower			Upper		
9.89	6.59	4.94	4.94	3.29	2.47

Web Data

t 0.346 d 9.60 Z_w 5.31

Reduced Flange Area

t	2.43	1.93	1.44	0.95	0.45	
1.5t	2.76	2.43	2.10	1.77	1.44	lower
2.0t	2.92	2.67	2.43	2.18	1.93	
t	1.21	0.97	0.72	0.47	0.23	
1.5t	1.38	1.21	1.05	0.88	0.72	upper
2.0t	1.46	1.34	1.21	1.09	0.97	

Reduced Section Modulus

t	27.074	21.565	16.056	10.546	5.037	
1.5t	30.235	26.306	22.377	18.449	14.520	lower
2.0t	31.816	28.677	25.538	22.400	19.261	
t	15.429	12.290	9.150	6.010	2.871	
1.5t	17.011	14.661	12.312	9.963	7.614	upper
2.0t	17.801	15.847	13.893	11.940	9.986	

Reduced Web Modulus

3.77	3.01	2.24	1.47	0.70

Length 300

Lower Span			Upper Span		

Position of Maximum Moment

Lower Span	Upper Span
4.1221	4.2051

Section Modulus

Beam Theory

Lower Span	Upper Span
31.395	18.619

Rule Value

Lower Span	Upper Span
78.400	46.400

Flange Area

Lower Span	Upper Span
5.74	3.07

Flange Width

Lower Span			Upper Span		
14.45	9.63	7.23	7.74	5.16	3.87

Web Data

t 0.397 d 12.00 Z_w 9.53

Reduced Flange Area

t	4.29	3.57	2.85	2.13	1.40	
1.5t	4.78	4.29	3.81	3.33	2.85	lower
2.0t	5.02	4.66	4.29	3.93	3.57	
t	2.30	1.91	1.53	1.14	0.75	
1.5t	2.56	2.30	2.04	1.78	1.53	upper
2.0t	2.69	2.49	2.30	2.11	1.91	

Reduced Section Modulus

t	58.659	48.788	38.918	29.047	19.177	
1.5t	64.439	57.459	50.479	43.498	36.518	lower
2.0t	67.329	61.794	56.259	50.725	45.188	
t	34.717	28.875	23.033	17.191	11.350	
1.5t	37.811	33.517	29.222	24.928	20.633	upper
2.0t	39.358	35.837	32.317	28.796	25.275	

Reduced Web Modulus

7.13	5.93	4.73	3.53	2.33

Length 400

Lower Span						Upper Span

Position of Maximum Moment

Lower Span	Upper Span
4.9417	5.0329

Section Modulus
Beam Theory

Lower Span	Upper Span
56.092	34.012

Rule Value

Lower Span	Upper Span
140.083	84.787

Flange Area

Lower Span	Upper Span
8.65	4.81

Flange Width

Lower Span			Upper Span		
19.29	12.86	9.64	10.73	7.15	5.36

Web Data

t .449 d 14.40 Z_w 15.50

Reduced Flange Area

t	6.72	5.76	4.79	3.83	2.87	
1.5t	7.37	6.72	6.08	5.44	4.79	lower
2.0t	7.69	7.20	6.72	6.24	5.76	
t	3.74	3.20	2.67	2.13	1.59	
1.5t	4.10	3.74	3.38	3.02	2.67	upper
2.0t	4.28	4.01	3.74	3.47	3.20	

Reduced Section Modulus

t	108.854	93.240	77.626	62.011	46.397	
1.5t	118.112	107.126	96.141	85.155	74.170	lower
2.0t	122.741	114.070	105.398	96.727	88.056	
t	65.886	56.435	46.984	37.533	28.082	
1.5t	71.034	64.158	57.281	50.405	43.528	upper
2.0t	73.608	68.019	62.430	56.840	51.251	

Reduced Web Modulus

12.05	10.32	8.59	6.86	5.13

Length 500

Lower Span		Upper Span
	Position of Maximum Moment	
5.7734		5.8942
	Section Modulus Beam Theory	
84.895		49.841
	Rule Value	
211.994		124.186
	Flange Area	
11.22		5.99

Flange Width

22.44	14.96	11.22	11.99	7.99	5.99

Web Data

t 0.50 d 16.80 Z_w 23.52

Reduced Flange Area

t	8.97	7.85	6.73	5.61	4.49	
1.5t	9.72	8.97	8.23	7.48	6.73	lower
2.0t	10.10	9.54	8.97	8.41	7.85	
t	4.79	4.19	3.60	3.00	2.40	
1.5t	5.19	4.79	4.39	3.99	3.60	upper
2.0t	5.39	5.09	4.79	4.49	4.19	

Reduced Section Modulus

t	169.595	148.396	127.196	105.997	84.797	
1.5t	182.160	167.243	152.326	137.409	122.492	lower
2.0t	188.492	176.667	164.891	153.115	141.340	
t	99.348	86.930	74.511	62.093	49.674	
1.5t	106.060	96.996	87.933	78.870	69.807	upper
2.0t	109.415	102.030	94.644	87.259	79.874	

Reduced Web Modulus

18.82	16.46	14.11	11.76	9.41

Length 600

Lower Span		Upper Span
	Position of Maximum Moment	
6.6057		6.7585
	Section Modulus Beam Theory	
122.049		69.733
	Rule Value	
304.742		173.670
	Flange Area	
14.27		7.45

Flange Width

28.54	19.03	14.27	14.89	9.93	7.45

Web Data

t .50 d 19.20 Z_w 30.72

Reduced Flange Area

t	11.42	9.99	8.56	7.14	5.71	
1.5t	12.37	11.42	10.47	9.51	8.56	lower
2.0t	12.84	12.13	11.42	10.70	9.99	
t	5.96	5.21	4.47	3.72	2.98	
1.5t	6.45	5.96	5.46	4.96	4.47	upper
2.0t	6.70	6.33	5.96	5.58	5.21	

Reduced Section Modulus

t	243.794	213.320	182.845	152.371	121.897	
1.5t	262.062	240.722	219.382	198.042	176.701	lower
2.0t	271.196	254.423	237.650	220.877	204.109	
t	138.936	121.569	104.202	86.835	69.468	
1.5t	148.466	135.964	123.262	110.660	98.058	upper
2.0t	153.231	143.012	132.792	122.573	112.353	

Reduced Web Modulus

24.58	21.50	18.43	15.36	12.29

Length 700

Lower Span | Upper Span

Position of Maximum Moment

Lower Span		Upper Span
7.4385	Position of Maximum Moment	7.6251
168.599	Section Modulus Beam Theory	94.125
420.941	Rule Value	234.317
17.69	Flange Area	9.05

Flange Width

35.38	23.58	17.69	18.10	12.06	9.05

Web Data

t 0.50 d 21.60 Z_w 38.88

Reduced Flange Area

t	14.15	12.38	10.61	8.84	7.09	
1.5t	15.33	14.15	12.97	11.79	10.61	lower
2.0t	15.97	15.03	14.15	13.27	12.38	
t	7.24	6.33	5.43	4.52	3.62	
1.5t	7.84	7.24	6.64	6.03	5.43	upper
2.0t	8.14	7.69	7.24	6.79	6.33	

Reduced Section Modulus

t	336.753	299.659	252.564	210.470	168.326	
1.5t	362.223	332.865	303.506	274.147	244.788	lower
2.0t	374.959	351.968	328.977	305.986	282.995	
t	187.453	164.022	140.590	117.158	93.727	
1.5t	200.483	183.565	166.648	149.731	132.814	upper
2.0t	206.997	193.337	179,677	166.018	152.358	

Reduced Web Modulus

31.1	27.22	23.33	19.44	15.55

Length 800

Lower Span		Upper Span
	Position of Maximum Moment	
8.2717		8.4937
	Section Modulus Beam Theory	
225.593		123.451
	Rule Value	
563.200		307.200
	Flange Area	
21.47		10.80

Flange Width

42.93	28.62	21.47	21.60	14.40	10.80

Web Data

t 0.50 d 24.00 Z_w 48.00

Reduced Flange Area

t	17.17	15.03	12.88	10.73	8.59	
1.5t	18.60	17.17	15.74	14.31	12.98	lower
2.0t	19.32	18.25	17.17	16.10	15.03	
t	8.64	7.56	6.48	5.40	4.32	
1.5t	9.36	8.64	7.92	7.20	6.48	upper
2.0t	9.72	9.18	8.64	8.10	7.56	

Reduced Section Modulus

t	450.560	394.240	337.920	281.600	225.280	
1.5t	484.907	445.760	406.613	367.417	328.320	lower
2.0t	502.080	471.520	440.960	410.400	379.800	
t	245.760	215.040	184.320	153.600	122.990	
1.5t	263.040	240.960	218.880	196.800	174.700	upper
2.0t	271.680	253.920	236.160	218.400	200.600	

Reduced Web Modulus

38.40	33.60	28.80	24.00	19.20

Length 900

Lower Span		Upper Span

Position of Maximum Moment

9.1051	9.3638

Section Modulus
Beam Theory

294.078	158.148

Rule Value

734.131	393.395

Flange Area

25.61	12.70

Flange Width

51.22	34.14	25.61	25.40	16.94	12.70

Web Data

t 0.50 d 26.40 Z_w 58.08

Reduced Flange Area

t	20.49	17.93	15.36	12.80	10.24	
1.5t	22.19	20.49	18.78	17.07	15.36	lower
2.0t	23.05	21.77	20.49	19.21	17.93	
t	10.16	8.89	7.62	6.35	5.08	
1.5t	11.01	10.16	9.31	8.47	7.62	upper
2.0t	11.43	10.80	10.16	9.53	8.89	

Reduced Section Modulus

t	587.305	513.892	440.479	367.066	293.652	
1.5t	632.375	581.497	530.619	479.741	428.863	lower
2.0t	654.910	615.299	575.689	536.078	496.468	
t	314.716	275.377	236.037	196.698	157.358	
1.5t	337.070	308.908	280.746	252.583	224.421	upper
2.0t	348.248	325.674	303.100	280.526	257.953	

Reduced Web Modulus

46.46	40.66	34.85	29.04	23.23

Length 1000

Lower Span					Upper Span

Position of Maximum Moment

9.9387	10,2354

Section Modulus
Beam Theory

375.101	198.650

Rule Value

936.346	493.978

Flange Area

30.11	14.75

Flange Width

60.22	40.15	30.11	29.50	19.67	14.85

Web Data

t 0.50 d 28.80 Z_W 69.12

Reduced Flange Area

t	24.09	21.08	18.07	15.06	12.04	
1.5t	26.10	24.09	22.08	20.07	18.07	lower
2.0t	27.10	25.60	24.09	22.58	21.08	
t	11.80	10.33	8.85	7.38	5.90	
1.5t	12.79	11.80	10.82	9.83	8.85	upper
2.0t	13.28	12.54	11.80	11.06	10.33	

Reduced Section Modulus

t	749.076	655.442	561.807	468.173	374.538	
1.5t	806.891	742.164	677.437	612.710	547.983	lower
2.0t	835.799	785.526	735.252	684.979	634.706	
t	395.182	345.784	296.387	246.989	197.591	
1.5t	423.506	388.270	353.034	317.798	282.563	upper
2.0t	437.668	409.513	391.358	353.203	325.048	

Reduced Web Modulus

55.30	48.38	41.47	34.56	27.65

APPENDIX D

Sample Calculations

Calculation of the Corrected Safety Factor

In section I it was shown that c may be considered as a fictitious safety factor. In this section a few sample calculations will be made to show how c is corrected to a truer representation of the factor of safety for the assumed end conditions.

The procedure will be to calculate the maximum moment in the beam, assuming the end conditions derived in section I, and using various loadings which tend toward the true hydrostatic load on the beam. The moment, thus calculated, will be compared with the value $5w\ell^2/48$ derived in section I as the moment assumed by the ABS rules. This ratio of the two moments will be used in the following equation to give a corrected value of the safety factor.

$$SF = cM_a/M_r$$

Where a represents the assumed value and r the calculated value.

In all cases the fundamental value of the rule moment shall be

$$M = 5w\ell^2/48$$

However, it must be remembered that as additional loads are superimposed on the beam, the loading increases causing the numerical coefficient to change.

It will be noted in all cases that as the uniform component of the load increases the true factor of safety approaches the value of c. This is as expected since c is based on the assumption of uniform loading.

a) A uniform beam with 25% and fixity at each end

Load	M_1	M_2	R_1	R_2
uniform	$w\ell^2/48$	$w\ell^2/48$	$w\ell/2$	$w\ell/2$
varying	$\rho s\ell^3/120$	$\rho s\ell^3/80$	$13\rho s\ell^2/80$	$27\rho s\ell^2/80$

Case a-1 will be for $w = 0$, that is, there is only a uniformly varying load.

$$M_x = \rho s \left\{ 13\ell^2 x/80 - \ell^3/120 - x^3/6 \right\}$$

$$dM/dx = 0 = 13\ell^2/80 - x^2/2$$

the point of maximum moment

$$x = 0.57\ell$$

the maximum moment is

$$M = 0.0535\rho s\ell^3$$

This value of moment is larger than either M_1 or M_2 and will therefore be used to correct the value of c.

$$SF = (5)\ (2.5)/(96)(0.0535) = 2.43$$

Case a-2 will be for a beam with the same end conditions as case a-1, but there shall be imposed a uniform load such that the total uniform load equals the total varying load, that is $w = \rho\ s\ell/2$. Adding the end moments for the two loads together the following results are obtained.

$M_1 = 9\rho s\ell^3/480$ $\qquad M_2 = 11\rho s\ell^3/480$

$R_1 = 33\rho s\ell^2/80$ $\qquad R_2 = 47\rho s\ell^2/80$

$$M_x = R_1 x - \rho\ s\ell x^2/4 - M_1 - \rho\ sx^3/6$$

the point of the maximum moment

$$x = 0.537\ell$$

the maximum moment is

$$M = 0.105\rho s\ell^3$$

This is larger than either M_1 or M_2 and is therefore used in the correction of c. Remember that the load is now double and therefore 5/48 and not 5/96 is the correct rule value to use.

$$SF = (5)(2.5)/(48)(0.105) = 2.48$$

b) A uniform beam 50% fixed at end 1 and fully fixed at end 2

The same two conditions of loading as in (a) are applied to this case. However, in both conditions of loading the end moments are larger than the moments in the beam and must be used in the correction of c.

The results of this calculation and of others for different end conditions are tabulated in appendix C.

Trial Solution of the Computer Problem

The purpose of the following solution is to check the solution obtained on the IBM 704 computer. Slide rule accuracy is deemed sufficient. The numbers in parenthesis refer to the equations of appendix A

a) $L = 1000$ $\quad t_f = 2t$ $\quad a = 0.15$

$B = 120$		(1)
$H = 48$		(2)
$h' = 8$		(3)
$\ell = 19.2$		(4)
$h_L = 40.64$	$h_u = 21.44$	(5)
$h''_L = 31.04$	$h''_u = 11.84$	(6)
$x_L = 9.96$	$x_u = 10.16$	(8)
$M_L = 1,005,000$	$M_u = 482,000$	(7)
$ZSBT_L = 377$	$ZSBT_u = 198.6$	(9)
$ZABS_L = 935$	$ZABS_u = 493$	(10)

$t = 0.50$ (11)

$d = 28.8$ (12)

$Z_w = 69.2$ (13)

$A_{fL} = 30.2$ $A_{fu} = 14.8$ (14)

$W_{fL} = 30.2$ $W_{fu} = 14.8$ (15)

$A'_{fL} = 21.1$ $A'_{fu} = 10.35$ (16)

$Z'_w = 27.5$ (17)

$Z'_L = 634.4$ $Z'_u = 324.4$ (18)

Two other check points were calculated. These were;

for the upper span with the flange thickness equal to web thickness, a corrosion allowance of .05, and a ship length of 200 feet; for the lower span with the flange thickness equal to one and one half times the web thickness, a corrosion allowance of .10, and a ship length of 500 feet.

$L = 200$	$L = 500$	
$B = 40$	$B = 70$	(1)
$H = 16$	$H = 28$	(2)
$h' = 4$	$h' = 8$	(3)
$\ell = 6.4$	$\ell = 11.2$	(4)
$h_u = 8.48$	$h_L = 27.04$	(5)
$h'_u = 5.28$	$h'_L = 21.44$	(6)
$x_u = 3.38$	$x_L = 5.76$	(8)
$M = 23,900$	$M = 227,000$	(7)
$ZSBT_u = 8.70$	$ZSBT_L = 85.0$	(9)
$ZABS_u = 21.7$	$ZABS_L = 212$	(10)

$t = 0.3457$	$t = 0.50$	(11)
$d = 9.6$	$d = 16.80$	(12)
$Z_w = 5.3$	$Z_w = 23.5$	(13)
$A_{fu} = 1.71$	$A'_{fL} = 11.2$	(14)
$W_f = 4.95$	$W_L = 14.9$	(15)
$A'_{fu} = 1.215$	$A'_{fL} = 8.2$	(16)
$Z'_w = 3.78$	$Z'_w = 14.1$	(17)
$Z' = 15.43$	$Z' = 151.6$	(18)

APPENDIX E

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ERRATA

AN EVALUATION OF THE AMERICAN BUREAU OF SHIPPING RULES FOR THE TRANSVERSE FRAMING OF TANKERS

page 2	line 2, correct spelling of computer
3	line 4, correct spelling of computer
6	fourth line from the bottom should read "The flange area (A)----"
10	line 8, insert comma after logical
10	ninth line from the bottom, change to read "---to SF. Assume k is ----"
11	line nine, add a comma after k and after constraint
12	line 1, change is to was
14	item 7, line 2, change rules to rule
28	line 2, change were to was
30	line 8, should read " figures II thru VIII
38	second and third line from the bottom, correct spelling on computer
54	line 12 and 14, correct spelling of computer
	line 15, change parenthesis to parentheses
	equation (6) left side should be h_L''